AMBIO (2010) 39:91–99
DOI 10.1007/s13280-010-0017-4

REVIEW PAPER

Agriculture as Provider of Both Food and Fuel

Kersti Johansson, Karin Liljequist, Lars Ohlander, Kjell Aleklett

Published online: 16 April 2010

Abstract A database of global agricultural primary production has been constructed and used to estimate its energy content. The portion of crops available for food and biofuel after postharvest losses was evaluated. The basic conditions for agriculture and plant growth were studied, to ensure sustainable scenarios regarding use of residues. The available energy contents for the world and EU27 was found to be 7,200–9,300 and 430 TWh, respectively, to be compared with food requirements of 7,100 and 530 TWh. Clearly, very little, or nothing, remains for biofuel from agricultural primary crops. However, by using residues and bioorganic waste, it was found that biofuel production could theoretically replace one-fourth of the global consumption of fossil fuels for transport. The expansion potential for global agriculture is limited by availability of land, water, and energy. A future decrease in supply of fossil energy and ongoing land degradation will thus cause difficulties for increased biofuel production from agriculture.

Keywords Biofuel · Bioenergy · Food security

INTRODUCTION

The region between the rivers Euphrates and Tigris is known as Mesopotamia and the northern part of this region is said to be the birthplace of agriculture. A surplus of food made it possible to develop cities as centers of trade and state administrations (http://looklex.com/e.o/mesopotamia.htm). Agriculture became fundamental for society then and remains so today.

Modern agriculture is dependent on oil and natural gas, but many also believe that it will provide part of the future substitutes for fossil fuels. This raises the question of whether agriculture does, in fact, have the capacity to provide us with both food and fuel.

Potential agricultural output is limited by the availability of farmland, water, and auxiliary energy. Further limitations are soil quality and the ability of surrounding ecosystems to cope with leakage from the agricultural systems. This is why it has been questioned whether ambitious policies such as the European Union's target of 10% biofuel of total fuel consumption in the transport sector by 2020 (http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/introduction) are achievable in a sustainable way.

Many attempts have been made to estimate future biofuel production, and some of these studies are presented in a report from the International Energy Agency (2004). The complexity of agricultural production causes estimated yields to vary widely due to different assumptions made on possible agricultural output, technology development, and changes in food demand. Rough generalizations simplify the calculations but make it hard to evaluate the feasibility of the conclusion, creating a situation where it is fairly easy to achieve a desired result by adjusting the inputs.

In order to circumvent these difficulties, this study aimed to survey present agricultural production to find a starting point for analysis. From the information obtained, conditions for current production are discussed, as are factors which may determine future development of agricultural biofuel production. Finally, the question whether agriculture can provide the world with both food and with feedstock to meet the growing demand for biofuel is addressed.

METHODOLOGY

To be able to compare agricultural production with the demand for food and fuel, data on primary production (i.e. harvested) and its energy content were gathered in a database. The energy content per weight unit of crop was calculated through the chemical composition of each crop. Thus, the energy content of a certain amount of crops could easily be evaluated.

Since all biomass produced on farmland would be of interest for fuel production, the amount of residues was calculated and included in the database. To be able to evaluate the amount of food produced and compare it with food demand, deductions from the total primary production were made for requirements of seed for reproduction, of postharvest losses in storage, and of losses in upgrading. Further, inedible crops and parts of crops had to be withdrawn.

All quantities were expressed in terms of calorimetric energy values to facilitate a comparison of agricultural production in relation to demands for food and fuel. Conversion factors for biomass into ethanol, biodiesel, and biogas were calculated and used to create different scenarios of possible biofuel production from agriculture. The energy content of all fossil fuel used in the transport sector was evaluated for comparison with the results from the calculations on agricultural and biofuel production. To get a picture of the possible future development of agricultural production, the sustainability and future expansion potential of the agricultural sector is discussed.

CALCULATION AND RESULTS

The constructed database includes data on agricultural production for every individual country, making it is possible to calculate the energy content of crops and residues for any region. We chose to present results for both the world and the 27 member states of the European Union, hereafter referred to as EU27, since it plans to significantly increase the amount of biofuel in the transport sector within the union.

Gross Energy Content of Primary Production

Statistics on agricultural production were taken from the database of the Food and Agriculture Organization of the United Nations (FAO) (http://faostat.fao.org/site/567/default.aspx#ancor). The data used refer to the world production in year 2006 and includes 129 different crops. The data were compared with the statistics for the 10 preceding years showing a slowly increasing production and in the report "Can agriculture provide us with both food and fuel—a survey of present agricultural production" by Johansson and Liljequist (http://www.tsl.uu.se/uhdsg/publications/agriculture.pdf) it was concluded that 2006 was a well-representative year (Johansson and Liljequist 2009, p. 24, Fig. 4.1.1).

In order to achieve a value on the total energy content of the global agricultural production, the energy content per mass unit for all different crops included in the database was required. This data was obtained from different estimations and calculations (Johansson and Liljequist 2009, Appendix 2). Common values for energy contents in different nutrients, for example, 17 MJ for carbohydrates, were obtained from the Swedish National Food Administration (http://faostat.fao.org/site/567/default.aspx#ancor) and used to assure consistency in the calculations. Crops for fiber, fodder, tobacco, natural rubber, coffee, and tea production were classified as inedible, as well as and parts of crops such as husks and nutshells, in order to compare this amount with the energy required to feed a given population.

To determine the energy content expressed in TWh units, Eq. 1 below was applied to every crop:

$$GE = PP * \frac{(EE * RE + EI * RI)}{3.6 * 10^9}, \qquad (1)$$

where GE is the gross energy content [TWh], PP primary production [tonnes], EE energy content of edible part [MJ/tonne], RE ratio of edible part [0:1], EI energy content of inedible part [MJ/tonne], and RI ratio of inedible part [0:1].

The calculation gave a total gross energy content of the global primary production as 19,900 TWh, of which 17,560 TWh was considered edible. The corresponding results for the EU27 were 2,100 TWh of which 1,600 TWh was edible.

Net Energy Production After Postharvest Losses

Different groups of crops have different kind of losses, and the brief descriptions in following sections summarizes which parameters were put into the database to calculate the net energy content of the agricultural production, i.e. the fraction of the gross primary production which is actually available for food. Most losses occur in storage, but large quantities, especially for fruit, tubers, and vegetables are also sorted out and considered not of good enough quality for consumption. On top of this, there are losses due to mechanical damages, in upgrading processes and waste in household. The latter is difficult to estimate, which is why this part was omitted from the calculations.

Seed for Reproduction

A certain percentage of the crop production, seed, tubers, and cuttings is needed for reproduction and is not available for other uses. Different percentages ranging between 0 and 10% of seed where estimated with calculations based on yields, grain mass, and recommended amount of seeds for reproduction use (Johansson and Liljequist 2009, Appendix 4).

Storage Losses

In storage, there is a certain amount of shrinkage in crop mass due to cell respiration. In addition, losses are caused by bacterial degradation as well as insect and rodent digestion. We summarized these losses as "lost losses" and estimated them to ~7% (Johansson and Liljequist 2009, pp. 32–33), of the gross production.

The approach of separating "lost losses" suggests that other losses, such as losses due to molds, leftovers after certain upgrading or damaged crops sorted out can still be used for animal feed or energy production. Mold attacked crops is by far the largest source of postharvest losses in storage. A range of 10–30% on global losses due to molds for cereals has been estimated (Chelkowski 1991). This range was assumed to be valid also for pulses, oil crops, and fodder crops. The amount of losses is heavily dependent on storage technology, climate, and type of crop. Therefore, losses tend to be larger in developing countries and smaller in industrialized countries. For the aforementioned crops, the losses due to molds were estimated to 20% globally. Since agriculture in the European Union is mostly industrialized, storage losses are assumed to be lower, why 10% was used in the calculations for EU27.

Production Discarded Due to Inferior Quality

Before marketing, parts with inferior quality of vegetables, fruits, roots, and tubers are sorted out. With aid of expertise on these crops, we estimated these losses to be in the range 15-20% (Johansson and Liljequist 2009, p. 34). The discarded production was used in the scenarios of biogas potential, see Sect. 3.4 below.

Initial Processing of Main Crops

For agricultural products to be available as food for humans, a certain processing is needed for several crops. For example, wheat can be milled into flour, processed into pasta, and boiled in the household. The initial processing is milling, leaving husks and bran as a by-product which makes up 20–30% of the cereal grain (Johansson and Liljequist 2009, Appendix 5). On the other hand, these by-products are commonly used as livestock feed or fiber sources in human food.

It was chosen to leave out further processing, only treating the initial phase such as extracting oil from oil crops, sugar from sugar crops, and milling cereals into flour. In this way, the actual edible energy content is calculated, whereas it is more or less a choice to further process food. This gives the processed product and the by-products, where the by-products are not preferably used as human food (even though they can in some cases be eaten), but as livestock feed.

Livestock Feed Concentrate

Domestic animals can eat what humans cannot eat and convert it into edible products, such as meat, milk, and eggs. The most important sources of feed are still grazing, forage, and silage, but due to increasing demand for animal products more concentrated feed is used. The energy needed is taken from cereals, and the protein sources are grain legume seeds and oil crop meals (Johansson and Liljequist 2009, Appendix 9).

Meat, Fish, and Seafood

Energy from livestock products, game meat, fish, and seafood is included to compare the total available amount of food with the amount of food required to feed the population. Data on livestock meat, egg, milk, game meat, fish, and seafood production were taken from FAO statistics (http://faostat.fao.org/site/567/default.aspx#ancor). The energy content of these products was collected from the Swedish National Food Administration food database (http://www7.slv.se/livsmedelssok/?epslanguage=sv).

Net Energy Calculation

In order to calculate the net energy content available for human food, Eq. 2 was used in the database:

$$\mathrm{NE} = \mathrm{GE} - \mathrm{S} - \mathrm{LL} - \mathrm{M} - \mathrm{D} - \mathrm{I} - \mathrm{FO} - \mathrm{FPC} + \mathrm{L} + \mathrm{G}, \tag{2}$$

where NE is the net energy production, GE gross energy content in primary crops, S energy content of seed used for reproduction, LL energy content of "Lost Losses," M energy content of food lost to mold, D energy content of discarded production, I energy content of inedible fraction after losses, FO energy content of oil crop meals used for animal feed, FPC energy content of peas and cereals used for animal feed, L energy content of meat, egg, and dairy products from livestock, and G energy content of game meat, fish, and seafood.

Two cases were considered. The high case assumes that all rest products after the initial upgrading (oil crop meals, husks, and bran from cereals and sugar crop fibers after sugar extraction) are available as food, giving NE as 9,265 TWh globally. However, the rest products are not preferably eaten, and in some cases they might even be uneatable or at least not digestible for humans. In the low case, it is assumed that the rest products in question are considered uneatable, replacing FO in Eq. 3 with the total energy content in the rest products after initial upgrading. The low case gives NE as 7,225 TWh. In EU27, the calculations show that all the rest products after upgrading are needed for livestock feed, and there is no difference between the high and the low case which both gives NE as 431 TWh. Table 1 below shows the absolute values of the parameters in Eq. 3 for both the global agricultural production and the production within EU27.

There is a large gap between the gross production and the net production. By far the largest loss is the feed concentrate from cereals. Another large loss is the mold damaged production, which on the other hand can be used for biogas production.

Comparison with Food Requirements

The energy requirement for a human being varies between 760 kcal/day for a newborn baby and 3,300 kcal/day for a regularly exercising 18–30-year-old male (http://www.slv.se/sv/grupp1/Mat-och-naring/Svenska-narings-rekommendationer/Referensvarden-for-energiintag-hos-grupper/). If an average of 2,500 kcal/day of food is assumed, the annual food requirement of the 6.7 billion world population would be 7,092 TWh. For the 497 million population of EU27, the annual food requirement would be 526 TWh.

The results for the global production show that the net energy production in both the high case and the low case will be more than enough to feed the global population assuming the requirements are 2,500 kcal/day, as seen in Table 2. However, again, the household losses are not included in these calculations, and this may in reality eliminate any potential surplus.

Table 2 also shows that the energy content of the agricultural production within EU27 in 2006 is not, according to our calculations, enough to cover food requirements, unless postharvest losses are reduced. One important factor contributing to the deficit is the extensive meat production. Table 1 above shows that meat production uses a large fraction of the cereal production, and this kind of processing of primary crops has a very low efficiency.

Table 1 Net energy production

Parameter	Global		EU27
	High case	Low case	
Gross energy	+19,900	+19,900	+2,100
Seed for reproduction	−700	−700	−70
Lost losses	−1,300	−1,300	−130
Food lost to mold*	−2,700	−2,700	−161
Discarded material	−360	−360	−26
Inedible fraction	−1,770	−1,770	−387
Feed of oil crop meal**	−690	−2,700	−160
Feed of grain legumes and cereals	−4,545	−4,545	−1,000
Livestock products	+1,183	+1,183	+265
Game meat, fish and seafood	+217	+217	
Net energy	9,265	7,225	431***

* Losses due to molds are assumed to be 20% in the global case, and 10% in EU27, for cereals, pulses, oil crops and fodder crops

** In the low case fodder from oil crop meals is replaced by total energy content in rest products after upgrading processes

*** In EU27, the energy content of the rest products after upgrading corresponds to the feed requirements, and there is no difference between the high and low case

Gross Energy Content of Residues

From Sect. 3.2 above, it can be concluded that there is not any large potential of making fuels from the present primary production when the figures are compared with the global food requirements. In fact, if a part of the primary production is taken for this purpose there will probably not be enough food to feed the global population, and even less so in the future with an expanding global population. Using residues on the other hand does not directly affect food availability, and therefore the potential of making fuels from residues was investigated. Since there is no data on the production of residues, it had to be calculated from the primary production through each crop's Harvest Index (HI) defined in Eq. 3:

$$\mathrm{HI} = \frac{\text{Primary product yield}}{\text{Total biomass above ground level}}. \tag{3}$$

Every crop in the database was given an individual value of HI (Johansson and Liljequist 2009, Appendix 3). It was not possible to find sources on HI for all crops, and in these cases estimates were made. All estimations and assumptions were elaborated through studying descriptions of the crops. We have in this way tried to arrive at the best possible values, and if in doubt used the higher estimates of HI to avoid an overestimation of available crop residues.

The residues have been divided into two categories: annual residues and perennial residues. The annual residues are those made up by crops grown as annuals, i.e., sown

Table 2 Food energy demand compared to production

Region	Population	Food energy demand (2,500 kcal per capita per day) [TWh]	Net edible production (high case) [TWh]	Net edible production (low case) [TWh]
Global	6.700×10^9	7,092	9,265	7,225
EU27	0.497×10^9	526	431	431

and harvested within a year or shorter time. The perennial residues are estimates of annual increment of perennial plants such as bushes or fruit trees. This distinction was important in the calculations for fuel production. For example, woody biomass (the perennial residues) is not appropriate to use for biogas production since they are too hard to digest. However, with new technology, such as second generation ethanol production, it might be possible to use these as feedstock.

The calculated total energy content in the gross residue production was 18,200 TWh in the global case and 1,500 TWh in EU27.

Biofuel Potential

An important question is how much residues can be removed from the fields without risking a decrease in humus content. This depends on many different factors such as soil type, climate, and agricultural methods, hence varying vastly throughout the world.

Two alternatives of fuel production from residues were considered: biogas and second generation ethanol production. For biogas production, only the annual residues were considered, whereas for ethanol production, both annual and perennial residues can be used.

It was assumed that two-thirds of the total residue production is technically harvestable. As regards biogas production, it was assumed that all technically harvestable residues can be used, since the rest products after biogas digestion contains nutrients and enough carbon not to unduly lower the humus content of the soils if it is all returned.

When ethanol is produced, the rest products may be returned to the field but as they are rich in protein this is less appropriate as they can be used as animal feed (Karlberg 2008). The manure from the animals may then be returned to the field, but the nutrient and carbon contents will be significantly less than in the case of biogas production. The rest products can also be used as heating fuel (Karlberg 2008), and it was assumed that there is no recycling of nutrients and carbon to the fields when residues are used for ethanol production. It this case the maximum limit of obtainable residues was assumed to be one-third of total residue production (Johansson and Liljequist 2009, p. 51).

Other fuels involving gasification of biomass, such as Fischer–Tropsch diesel or methanol, may in the future become a better alternative than ethanol when it comes to efficiency. However, any rest products will probably not return more nutrients to the field than in ethanol production, and taking more than one-third of the residues would not be appropriate in these cases either.

The fuel yields in TWh units were calculated in the database by multiplying the fuel yield for each kind of crop or residue with its energy content and production weight (Johansson and Liljequist 2009, pp. 53–65).

The potential of biogas from residues is 4,340 TWh in the global case and 440 TWh in EU27 (Johansson and Liljequist 2009, p. 59, Table 7.1.6). For ethanol production, the corresponding figures were 3,300 TWh globally and 214 TWh in EU27 (Johansson and Liljequist 2009, p. 62, Table 7.2.3). Some losses, i.e., the losses due to molds or the production discarded due to inferior quality, can be used for biogas production. Also the inedible part of no other use, such as nutshells and husks, can be used for this purpose. Adding the possible biogas production from these sources would give a total biogas potential of ~6,500 TWh (Johansson and Liljequist 2009, p. 56, Table 7.1.3; p. 57, Table 7.1.4).

Analysis of Results

Fossil fuels constitute 98% of the total energy consumption in the transport sector which corresponds to about 25,000 TWh. At present, the most important substitutes for fossil motor fuels on the market are biofuels, especially ethanol made from agricultural products. So far these renewable fuels only make up for about 1% of the global transportation fuel consumption (International Energy Agency 2008, p. 37).

In Fig. 1 below, the consumption of fossil fuels in the transport sector that must be replaced is compared with our results. The energy content of the global primary production is only 80% of the global energy consumption for transportation. Almost half the gross energy content from the primary production is lost in storage and upgrading in the high case which is presented in Fig. 1. Figure 1 also shows that the net energy production from primary products covers the global food demand with a small surplus if 2,500 kcal per person is required each day.

Since the edible fraction is required as food, the potential biofuel production lies in using inedible fractions such as damaged material and residues. If losses in storage and residues are used for biogas production, 6,501 TWh or approximately one quarter of all fossil transport fuels can be replaced. If the residues are used for ethanol production instead, it is possible to obtain 3,300 TWh ethanol.

It has been argued that making ethanol from sugarcane will make us significantly less dependent on fossil fuels (Nguyen et al. 2009). However, if all sugarcane in the world would be used for ethanol production, there will first not be enough food and secondly the amount of fossil fuels that can be replaced is not more than 620 TWh (2.5% of world total). If the IEA forecast of having mainly ethanol replacing 7% of the global transport fuel in 2030 is to become real (International Energy Agency 2006), it would mean almost a tripling of the total acreage of sugarcane and

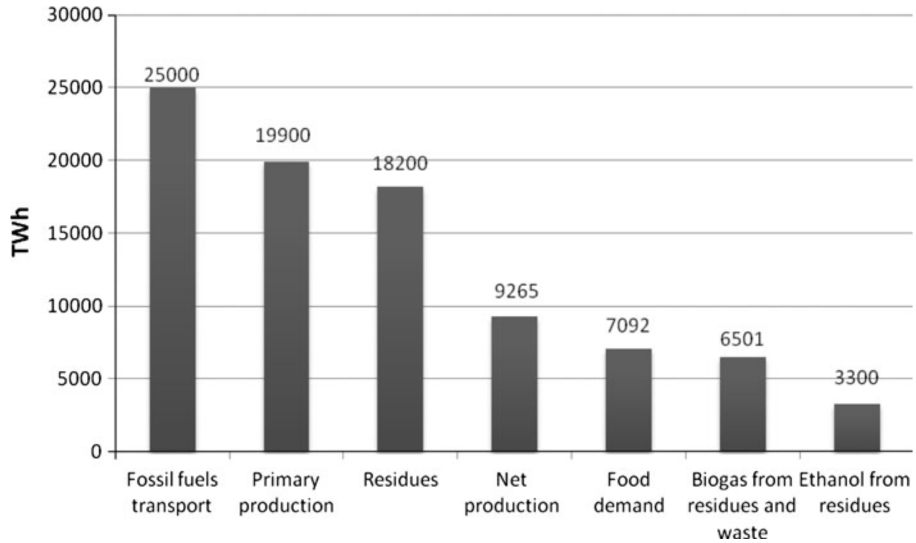

Fig. 1 Global agricultural production and some scenarios for possible biogas and ethanol production compared to present consumption of fossil motor fuels and global food demand

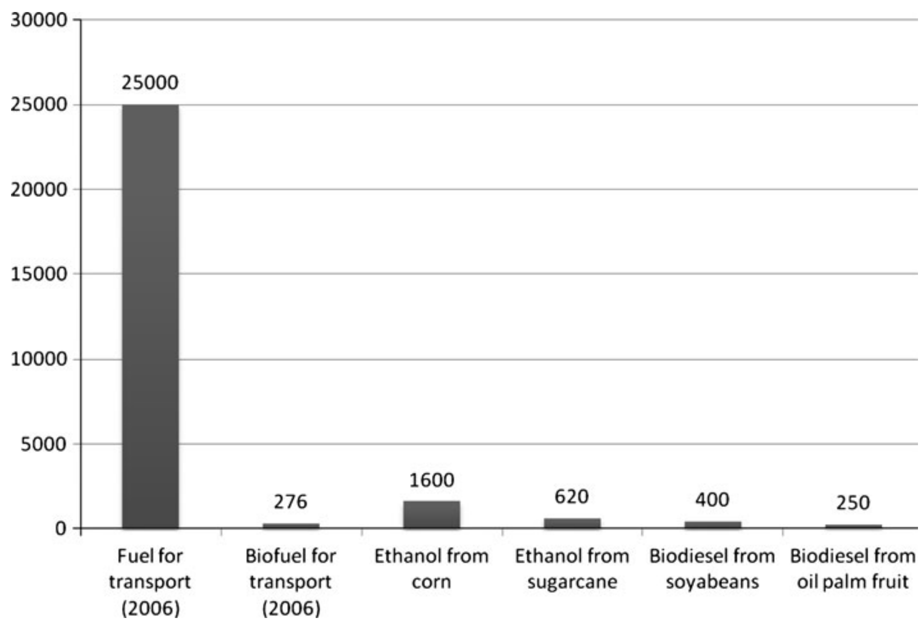

Fig. 2 The amount of biofuel produced if the total global production of certain crops was used as feedstock, compared to the consumption of biofuel and fossil fuels within the transport sector in year 2006, given by the International Energy Agency (2008, p. 37)

using all sugarcane for ethanol production. In Fig. 2, some more examples are given where the total world production of different crops are used for fuel production. Since biomass looses energy in the conversion into liquid fuels, there is a larger input energy in form of crops than the energy content of the fuel. In the database calculation, it was found that a total removal from food production to fuel production of any of the crops in Fig. 2 would have the consequence that the global food production will not be enough to feed the world's population.

DISCUSSION

Today motor biofuel is produced mainly from primary agricultural production, but how can we expect the situation to change in the future? Can global agriculture expand in such an extent that it can provide a growing population with both food and fuels, or are such expectations unrealistic?

The conditions for agriculture differ widely around the world. Soil quality and water availability as well as the level of industrialization determine yields on worldwide farmland. The so-called green revolutions has enabled increased yields and decreased labor requirements simultaneously through providing farmers with mineral fertilizer and tractors run on fossil fuels (Pimentel and Hall 1989, p. 34). Although this development has made it possible to provide an ever increasing world population with food, it has also made the agricultural system increasingly dependent on supply of external energy, especially fossil energy, and water for irrigation. Figure 3 shows the changes in

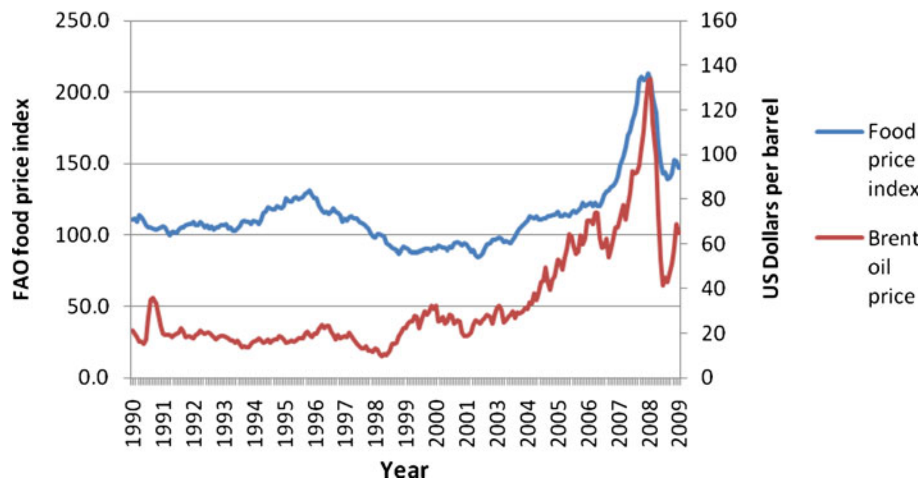

Fig. 3 Food and oil prices 1990–2009

food and oil prices during the period 1990–2009. The trends seem to correspond rather well which is likely due to the large requirement of auxiliary energy in modern agriculture. A study on the U.S. food system shows that as much as 7.3 units of energy, mostly from fossil fuels, are consumed to produce one unit of food energy (Heller and Keoleian 2000, p. 46).

The supply of energy and water resources will thus set the limits for a similar development in other non-industrialized parts of the world. Since fossil energy is a finite resource (Robelius 2007, p. 136), it will not be sufficient for an ever increasing food demand. Moreover, the amount of water used for irrigation is approaching its theoretical limit (Falkenmark and Rockström 2008, p. 11). Extensive unsustainable farming causes depletion of water reservoirs, as well as contamination of soils with salts from irrigation water and degradation of farmland by removing more nutrients than are replaced. Such development indicates that in some regions, yields are more likely to decrease than increase. As for the financially poor farmer, decreased yields makes it necessary to put more land into production, land that is often margin land of poor quality such as steep hillsides causing even more damage when put into production.

Lack of good quality land for agriculture is often the cause of deforestation when new land is made arable to increase production. Agriculture, forests, natural ecosystems, industries, cities, and roads all compete for land and expanding one of these sectors inevitably results in removing land from another sector. What is considered arable land is also a matter of definition. Margin land can be made arable with enough energy input and forests and natural ecosystem can be turned into good quality farm land. But is that desirable? Deforestation and a decreasing biodiversity are already causing concern and damage, as more land is being turned into cropland, in form of desertification, erosion and loss of ecosystem services such as clean water.

This limited supply of land, water, and fossil energy indicates that it can be considered extraordinarily optimistic to expect agricultural output to increase dramatically, something that would be required if an increasing world population is supposed to be provided with both food and motor fuels from agriculture in the future. With the present rate of population increase, food security in itself will be enough of a challenge for future agriculture.

With present technology, biomass with high content of starch or sugar is required as feedstock for biofuel production, leaving us with using agricultural crops, which is why it was of interest in this study to survey only feedstock from agriculture. In the future, cellulosic matter will probably be used for biofuel production to a greater extent as a result of the development of new technology. Therefore, the potential of second generation ethanol production from residues was investigated as well (Fig. 1). However, this development might also lead to forests playing an even more prominent role in future energy systems, provided they are not converted into farmland.

New technology will probably increase efficiencies of the biofuel production processes as well and the development of new types of crops might also change the conditions for the future production of agriculture and biofuels. For example, there is ongoing research on whether crops can be genetically modified to give better yields in harsher conditions and on poorer soils. However, even with such new technologies, soil fertility, water availability, and fossil fuels will impose narrow limits to the potential of future production. Because of the energy dependency of the agricultural system, any possible energy production from agriculture might be needed within the own sector, and not exported to the transport sector.

CONCLUSION

If the present agricultural system is to provide the present and the future world population with enough food, there is not much room for wasting any edible fraction or using it for biofuel. The result of the calculations shows that if the leftovers after upgrading processes are considered to be inedible, the present production is just about enough to supply everyone with 2,500 kcal per day, which is a feasible average for all humans. As for EU27, the food produced is not even enough to cover demand and imports are required. The fact that the losses within the household have been ignored makes the real food surplus even smaller and probably nonexistent. Thus, present production of edible crops cannot be used for biofuel production without threatening food security. One important way of increasing the net production within the present agricultural system is to reduce postharvest losses and losses through refinement processes of primary products. The latter can be accomplished, for example, through a change in diet to less processed foods, and meat production is in this context also considered as a refinement process.

The greatest potential for biofuel production within the present agricultural system lies in using inedible fractions such as residues and organic waste, e.g., mold attacked matter and crops of inferior quality. Biogas production has a greater potential than ethanol production since a higher proportion of the residues can be used for energy production. The calculated global potential of biogas production is in theory sufficient to cover up to one-fourth of the present consumption of fossil fuels within the global transport sector. However, there are infrastructural challenges with biogas production and distribution, and it is expensive to upgrade to motor fuel quality. Hence biogas could possibly be of better use in other applications than as motor fuel. Using it within agriculture could reduce agriculture's dependency on fossil energy, improving food security.

In principle, more low quality land can be made arable, but a future decrease in supply of fossil energy, limited water resources, and nutrient availability limits this potential. Current production is sufficient to feed the global population, thus famine is more or less a matter of equitable distribution of food. If large amounts of crops instead are used for biofuel production, it will not only be a question of equity, but also an actual deficit of food. If biofuel will become a necessity in the future energy system, it is crucial that vehicles will not “eat” our food.

Acknowledgments The authors would like to thank the following members Viktor Aguilar, AgrD, Universidad Nacional Agraria (UNA), Managua, Nicaragua, Johan Ascard, AgrD, Swedish board of Agriculture (Jordbruksverket), Kristina Belfrage, PhD, Swedish University of Agricultural Sciences (SLU), Bengt Bodin, AgrD, SLU, Birgitta Båth, AgrD, Department of Crop Production Ecology, SLU, Mr. P.O. Crona, Nordmills, Mr. Mats Edström, Institute of Agricultural and Environmental Science (JTI), Professor Per-Anders Hansson, Department of Energy and Technology, SLU, Professor Larry Hughes, Energy Research Group, Department of Electrical and Computer Engineering at Dalhousie University, Halifax, Professor Emeritus Sven Kullander, Royal Swedish Academy of Sciences, Professor Jan Erik Lindberg, Department of Animal Nutrition and Management, SLU, Professor Mats Olsson, Department of Soil and Environment, SLU, Professor Emeritus Jan Persson, SLU, Francisco Salmeron, AgrD, UNA, Donald Schmidt, PhD, Mr. Telémaco Talavera, president of UNA.

REFERENCES

Chelkowski, J. ed. 1991. Cereal grain, mycotoxins, fungi and quality in drying and storage. In *Developments in food sciences*, vol. 26. Amsterdam: Elsevier Science Publishers B.V.

European Commission. Eurostat. http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/introduction [Online]. Cited 01 September 2009.

Falkenmark, Malin, and Rockström, Johan. 2008. Is there sufficient water to eradicate hunger worldwide? A misleading question. In *Agriculture trade and development—Toward greater coherence*. Published by Royal Swedish Academy of Agriculture and Forestry (KSLA).

Food and Agriculture Organization of the United Nations. FAOSTAT—Agriculture. http://faostat.fao.org/site/567/default.aspx#ancor [Online]. Cited 26 March 2009.

Heller, Martin C., and Keoleian, Gregory A. 2000. *Life cycle-based sustainability indicators for assessment of the U.S. food system.* Ann Arbor, MI: Center for Sustainable Systems, University of Michigan. CSS00-04.

International Energy Agency. 2004. Biofuels for transport—An international perspective.

International Energy Agency. 2006. World energy outlook 2006: Fact sheet-biofuels.

International Energy Agency. 2008. Key world energy statistics 2008.

Johansson, Kersti, and Liljequist, Karin. 2009. Can agriculture provide us with both food and fuel? A survey of present agricultural production. http://www.tsl.uu.se/uhdsg/publications/agriculture.pdf [Online]. UPTEC ES09 011.

Karlberg, Lars Anders. 2008. Halm i tryckkokare ger billigare etanol. *Ny Teknik.* 21 August 2008.

Kjeilen, Tore. Mesopotamia. http://looklex.com/e.o/mesopotamia.htm [Online].

Nguyen, Thu Lan T., Hermansen, John E., and och Sagisaka, Masayuki. 2009. Fossil energy saving potential of sugar cane-bio-energy systems. *Applied Energy* 86: S132–S139.

Pimentel, David, and Hall, Carl W. 1989. *Food and natural resources.* San Diego, CA: Academic Press. ISBN 0-12-556555-0.

Robelius, Fredrik. 2007. Giant oil fields—The highway to oil. Giant oil fields and their importance for future oil production, no. 69. Uppsala Dissertations, Faculty of Science and Technology, Uppsala University, Uppsala.

The Swedish National Food Administration. Livsmedelsdatabasen. http://www7.slv.se/livsmedelsok/?epslanguage=sv [Online]. Cited 17 March 2009.

The Swedish National Food Administration. Referensvärden för energiintag hos grupper. http://www.slv.se/sv/grupp1/Mat-och-naring/Svenska-narings-rekommendationer/Referensvarden-for-energiintag-hos-grupper/ [Online]. Cited 19 August 2009.

AUTHOR BIOGRAPHIES

Kersti Johansson (✉) has a Master of Science in Energy Systems from Uppsala University and SLU.
Address: Global Energy Systems, Department of Physics and Astronomy, Uppsala University, Box 535, 751 21 Uppsala, Sweden.
e-mail: kersti.johansson@fysast.uu.se

Karin Liljequist is a Master of Science in Energy Systems from Uppsala University and SLU.
Address: Global Energy Systems, Department of Physics and Astronomy, Uppsala University, Box 535, 751 21 Uppsala, Sweden.
e-mail: karin.liljequist@gmail.com

Lars Ohlander is Associate professor (retired) in crop husbandry at the department of crop production ecology at the Swedish University of Agricultural Sciences (SLU).
Address: Department of Crop Production Ecology, Swedish University of Agricultural Sciences (SLU), Box 7043, 750 07 Uppsala, Sweden.
e-mail: lars.ohlander@vpe.slu.se

Kjell Aleklett is Professor of Physics and leader of the Global Energy Systems Group at Uppsala University, Sweden.
Address: Global Energy Systems, Department of Physics and Astronomy, Uppsala University, Box 535, 751 21 Uppsala, Sweden.
e-mail: kjell.aleklett@fysast.uu.se